Aboveground litterfall in Eurasian forests

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Abstract: With a data set of Eurasian forest litter fall based on 471 stands, annual litterfall was estimated to be 6.53 Pg dm $\cdot a^{-1}$ (1 Pg = 10^{15} g; dm, dry matter) in Eurasian forests, of which more than half occurred in tropical and subtropical forests, and a third in the boreal area. With litterfall, around 2.94 Pg C per year is transferred from the forest vegetation to the soil on this continent.

Keywords: Carbon flux; Eurasian forests; Litterfall

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Introduction

Litter fall, transferring organic matter and energy from the vegetation to the soil, is one of the major global carbon fluxes. In forest ecosystems, aboveground litter includes mainly foliage, branches, bark, and reproductive organs, and usually, foliage litterfall occupies a major fraction of total litterfall. At a continental or global scale, the synthesis of litterfall data is important for estimating and explaining quantitative litterfall, as well as its pattern.

The Eurasian continent comprises a variety of climatic conditions and forest vegetation (Ahti *et al.* 1968; Hou 1982; FAO 2001). Eurasian forests currently cover around 1.5 billion hm^2, or 41% of the total global forest area (FAO 2001) and thus play an important role in global carbon cycle. In the context of forestry management as a strategy to sequestrating carbon in forest ecosystem, it is necessary to quantify the litterfall to obtain a better understanding of carbon dynamics in Eurasian forests.

Litterfall on the forest stand level has been long observed in European forests (see Rodin & Bazilevich 1967). During the period of the International Biological Program (IBP), litterfall data were collected also at some sites of Japanese and Asian tropical forests (Deangelis *et al.* 1981; Cannell 1982). Since the beginning of the 1980s, a lot of litterfall investigations have been conducted in Chinese (Zhou 1995) and Indian forests (Dadhwal *et al.* 1997). Most of these litterfall data have not yet been synthesized at a continental scale. In this synthesis, our main objectives are to estimate the annual litterfall in Eurasian forests, and to determine the difference in litterfall between types of forests in different biomes.

Methods

Data Collection

To obtain original publications over litterfall in Eurasian forests, Forestry Abstract (1960s to 1998), and main forestry English-language journals (up until 1999) were searched, as well as some major reviews (Bray & Gorham 1964; Rodin & Bazilevich 1967; Cannell 1982; Proctor 1984; Berg *et al.* 1993; Dadhwal *et al.* 1997). To obtain data for China's forests, we surveyed main Chinese forestry publications from 1980 until 1998. All literature from which the data has been cited is listed in Appendix A.

In the data compilation, some criteria were followed. We used the data of forested areas (FAO 2001) to estimating litterfall in various forest groups, so the sample stands for which litterfall data was obtained in this study meet the definition of forest of FAO (2001). Stands, which had been fertilized or disturbed by forestry practice, e.g. thinning, or by e.g. fire, were not included. In the stands used, litterfall should have been collected for at least 1 year, and for the stands with the litterfall data of 2 years or more, mean values were used.

Estimating annual litterfall

Based on an identification of ecological zones (FAO 2001), the continent's climates were classified into five domains, namely tropical, subtropical, temperate, boreal, and arctic, and the forests in each such domain were subdivided into forest types according to precipitation, temperature, and altitude. In the boreal forest the subgroup arctic forest and in tropical, subtropical and temperate areas the subgroups, steppe and desert, were excluded. Boreal forests in Europe and Asia were combined into one group, mainly due to a lower number of data in these forest

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types. In all 13 groups of forests were used in estimating litterfall (Table 1). The area covered by each group was obtained as based on FAO's data set (FAO 2001). Correspondingly, we combined the stands from which our litterfall data were collected into 13 groups according to their geographical location, altitude, temperature, and precipitation. Mean annual total and leaf litter fall were calculated for each group and multiplied with the area of this forest group resulting in litterfall for that group on the whole continent.

Table 1. Forest groups and the areas in estimating total litterfall in Eurasian forests.

Forest groups	Forest area (million hm^2)
Tropical[1]	
Rain forest (A)	147.92
Moist (A)	36.56
Dry (A)	59.39
Mountain (A)	34.06
Subtropical[2]	
Humid (A)	78.42
Dry (A)	4.00
Mountain (A)	54.42
Dry (E)	29.30
Temperate[3]	
Continental (A)	45.89
Mountain (A)	37.93
Continental (E)	185.86
Oceanic (E)	28.29
Boreal[4]	
Boreal (AE)	793.54
Total	
Total Eurasian forests	1535.57

[1]Not including the shrub (8.14 million hm^2) and desert types (1.89 million hm^2); [2]Not including steppe (3.23 million hm^2) and desert (0.52 million hm^2) types; [3]Not including steppe (28.79 million hm^2) and desert (3.30 million hm^2) types; [4]Not including arctic types (7.11 million hm^2). Boreal (AE) contains coniferous, tundra and mountain types.

The letter A or E after the name of a forest group means that the group was located in Asia or Europe. The area of each forest group was based on FAO (2001).

Results

Total litterfall ranged from 572 $g \cdot m^{-2} \cdot a^{-1}$ in the Asian (A) dry forest to 973 $g \cdot m^{-2} \cdot a^{-1}$ in the rain forest in the tropical area, and the proportions of leaf litter in total litterfall ranges from 53% to 73% (Table 2). Total litterfall ranged from 438 $g \cdot m^{-2} \cdot a^{-1}$ in the European (E) dry forest to 617 $g \cdot m^{-2} \cdot a^{-1}$ in the Mountain (A) forest with a leaf litter fraction of 70% to 79% in the subtropical area. In the temperate area, total litterfall was 311 $g \cdot m^{-2} \cdot a^{-1}$ in the Asian continental forest to 469 $g \cdot m^{-2} \cdot a^{-1}$ in the European continental forest and the leaf litter was 64%-87% of total litterfall. In the boreal forest, total and leaf litter fall were 261 $g \cdot m^{-2} \cdot a^{-1}$ and 188 $g \cdot m^{-2} \cdot a^{-1}$, respectively, the latter being 72% of the former.

Both the range of litterfall in a forest group and the standard deviation shows a great variation among different stands within a forest group (Table 2). For instance, in the Asian rain forest, the total litterfall ranged from 340 $g \cdot m^{-2} \cdot a^{-1}$ to 1490 $g \cdot m^{-2} \cdot a^{-1}$, the highest thus being fourfold higher than the lowest. In the moist forest (A), the standard deviation is greater than half of the mean value (Table 2).

Table 2. Average total litterfall and leaf litterfall in different forest groups in Eurasian forests, given as $g \cdot m^{-2} \cdot a^{-1}$.

Forest groups*	Leaf litter			Total litterfall		
	Mean± sd	Range	n	Mean±sd	Range	n
Tropical						
Rain forest (A) (1)	622±171	270-1075	39	973±260	340-1490	64
Moist (A) (2)	473±225	145-1070	24	714±355	300-1510	29
Dry (A) (3)	416±194	240-894	12	572±239	326-1205	15
Mountain (A) (4)	422±127	230-570	6	793±277	360-1250	17
Subtropical						
Humid (A) (5)	384±164	176-829	59	539±219	239-1300	64
Dry (A) (6)	380±167	84-620	21	482±267	101-1060	20
Mountain (A) (7)	443±185	167-910	17	617±208	346-1178	17
Dry (E) (8)	307±127	80-530	19	438±191	174-770	19
Temperate						
Continental (A) (9)	198±91	79-334	18	311±120	92-524	23
Mountain (A) (10)	312±99	219-567	10	360±129	167-667	6
Oceanic (E) (11)	301±74	125-440	28	356±95	210-671	40
Continental (E) (12)	352±108	116-520	16	469±178	233-1180	31
Boreal						
Boreal (E, A) (13)	188±77	23-374	83	261±108	27-508	120

Note: The letter A or E after the name of forest groups in the first column means this group is located in Asia or Europe and the number indexes the references used. The data used in this analysis were based on those of Appendix A. The numbers in the following notes refer to the papers listed in Appendix A.

(1) Paper 14-15, 17, 34, 43-45, 63, 66, 78-79, 88, 97, 100, 118 & 136.
(2) Paper 21, 23-24, 52, 64, 68-69, 78, 95, 100-101, 113, 128, 144-145.
(3) Paper 2, 5, 16, 23, 42, 53 & 128.
(4) Paper 10, 48, 51, 58, 69, 97, 128 & 146.
(5) Paper 1, 4, 35-37, 55, 61-62, 65, 82, 84, 86-87, 91, 117, 123, 129, 132-135, 142, 144, 148 & 151.
(6) Paper 6, 40, 42, 92, 102, 114, 119-122, 124, 130-131 & 149.
(7) Paper 19-20, 41, 59, 93, 105-107 & 115.
(8) Paper 10, 39-40, 51, 81 & 138.
(9) Paper 7, 22, 27-28, 67, 116, 140-141, 143, 147 & 150.
(10) Paper 22, 29, 49, 56, 60 & 81.
(11) Paper 9, 25-26, 30-32, 75-76, 103 & 126-127.
(12) Paper 8, 13, 32, 46-47, 54, 77, 108 & 125.
(13) Paper 3, 8-9, 11, 13, 26, 32-33, 57, 70-74, 83, 89-90, 94, 99, 104, 110-112 & 138-139.

Over all Eurasia, the forested area is today more than 1 500 million hm^2 (excluding arctic and desert forests), half of which was boreal forest (Table 1). Total litterfall was around 6.53 Pg dry matter per year, of which more than the half is produced in Asian tropical and subtropical forests,

and a third in the Eurasian boreal forests (Table 3). In the tropical area, most of the litterfall occurs in the rain forest (1.44 $Pg \cdot a^{-1}$), and from 0.26 $Pg \cdot a^{-1}$ to 0.34 $Pg \cdot a^{-1}$ is produced in the other three forest types. On the average leaf litter constituted 71% of the total litterfall in Eurasian forests.

Table 3. Annual leaf litter and total aboveground litter production in Eurasian forests (10^{15} $g \cdot dm \cdot a^{-1}$, mean ± s.d.).

Forest groups	Leaf litterfall	Total litterfall
Tropical		
Rain forest (A)	0.92±0.25	1.44±0.38
Moist (A)	0.17±0.08	0.26±0.13
Dry (A)	0.25±0.12	0.34±0.14
Mountain (A)	0.14±0.04	0.27±0 09
Subtotal	1.48	2.31
Subtropical		
Humid (A)	0.32±0.13	0.42±0.17
Dry (A)	0.02±0.01	0.02±0.01
Mountain (A)	0.24±0.10	0.34±0 11
Dry (E)	0.09±0.04	0.12±0 05
Subtotal	0.67	0.94
Temperate		
Continental (A)	0.13±0.06	0.14±0.06
Mountain (A)	0.11±0.01	0.14±0.05
Oceanic (E)	0.08±0.02	0.10±0.03
Continental (E)	0.71±0.13	0.87±0.33
Subtotal	1.03	1.25
Boreal		
Boreal (AE)	1.49±0.61	2.07±0.85
Total Eurasian	4.66	6.53

Discussion

Our estimate shows that litter production in Eurasian forests is 6.53 Pg dry mass per year, and that foliage litter occupies a major fraction (53% to 87%) (Table 2). The concentration of carbon in leaf litter ranges from 40% to 55% (e.g. Upadhyay 1990, 1993; van Wesemael 1993; Johansson 1994; Pardo *et al.* 1997; Fioretto *et al.* 1998), and this variation is not related to forest groups. To simplify the calculations, we use 0.45 as a conversion factor from litter dry matter to carbon. Thus, the carbon flux in the forest litter fall was estimated to approximate 2.94 Pg C per year.

Compared with other biomass components (e.g. stem wood, coarse branches etc.), fine litter (leaf, reproductive organs, twigs etc.) has a much higher turnover rate. Meentemeyer (1986) showed that the first-year mass-loss of fresh leaf litter ranged from 30% in boreal to 80% in tropical areas and corresponding amounts of C will be released. Today we still do not know what fractions of litter that is transferred to humus but just the mass loss on the first year is considerable. In the context of global warming, forestry management has been accepted as a strategy to mitigating atmospheric CO_2 (IGBP Terrestrial Carbon Working Group 1998). In terms of carbon-fixing and carbon-sequestering efficiencies of a forest ecosystem, litterfall and the litter turnover should be taken into account.

The global forested area was 3.44×10^9 hm^2 in the 1990s, of which half was tropical forests (1.79×10^9 hm^2) (FAO 1995). Eurasian forests made up about 1.50×10^9 hm^2, being 41% of total global forests. Of the latter, boreal forests occupied a fraction of 57%, and tropical forests 26%. Global terrestrial litter production was estimated to 39×10^{15} $g \cdot a^{-1}$ (Matthews 1997) to 54×10^{15} $g \cdot a^{-1}$ (Meentemeyer *et al.* 1982), and global forest litter production was estimated to be 29×10^{15} $g \cdot a^{-1}$ (Lonsdale 1988). Our estimate showed that Eurasian forest litterfall is about one fifth of that of global forests and one ninth of that of terrestrial ecosystems. The fraction of Eurasian forest litterfall in global forest litterfall is thus much less than the fraction of Eurasian forest area of the global forest area. This may be explained by the fact that almost 60% of forests in the Eurasian continent are boreal, and that tropical forests occupy a correspondingly smaller part (27%).

We collected as complete and updated litterfall data as possible. In particular, most of the data including litterfall information in Chinese forests were published in Chinese, and thus for the first time used in a synthesis at a continental scale. For Eurasian forest litterfall, the data in our study is the most complete set published up until now. Compared with other litterfall estimates at a big geographical scale (e.g. Lonsdale 1988; Matthews 1997), the present estimate has the most abundant data set (litterfall data from 471 stands). In our analysis, we realized that more litterfall data at the stand level need to be investigated in Eurasian forests, especially in Russian boreal forests in Asia to allow more accurate estimates in the future.

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